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Macrophyte communities of European streams with altered physical habitat

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Abstract

The impact of altering hydro-morphology on three macrophyte community types was investigated at 107 European stream sites. Sites were surveyed using standard macrophyte and habitat survey techniques (Mean Trophic Rank Methodology and River Habitat Survey respectively). Principal Components Analysis shows the macrophyte community of upland streams live in a more structurally diverse physical habitat than lowland communities. Variables representing the homogeneity and diversity of the physical environment were used to successfully separate un-impacted from impacted sites, e.g. homogeneity of depth and substrate increased with decreasing quality class for lowland sites (ANOVA $p < 0.05$). Macrophyte attribute groups and structural metrics such as species richness were successfully linked to hydro-morphological variables indicative of impact. Most links were specific to each macrophyte community type, e.g., the attribute group liverworts, mosses and lichens decreased in abundance with increasing homogeneity of depth and decreasing substrate size at lowland sites but not at upland sites. *Elodea canadensis, Sparganium emersum* and *Potamogeton crispus* were indicative of impacted lowland sites. Many of the indicator species are also known to be tolerant to other forms of impact. The potential for a macrophyte tool indicative of hydro-morphological impact is discussed. It is concluded one could be constructed by combining indicator species and metrics such as species richness and evenness.

Introduction

Aquatic macrophytes are considered as sensitive to physical alteration in streams. Here, in response to management needs, that sensitivity is assessed on a pan-European basis for the first time. The European Union (EU) requires member states to categorise the quality of their rivers, primarily using aquatic organisms (European Commission, 2000). Macrophytes are included on the list of organisms, as are fish, invertebrates, phytobenthos and phytoplankton. Alterations to a river, including physical alteration, that degrades the biota and causes a site to be categorised as impacted must be mitigated against.

The underlying aim of the new legislation, the Water Framework Directive (WFD), is to manage aquatic systems by catchment using measures of ecosystem health to assess success (Pollard & Huxham, 1998). The inclusion of hydro-morphology in the assessment of ecological status is significant. In the past monitoring in running water has focused on chemical parameters and benthic invertebrates. The WFD now widens that focus and implicitly requires that habitats are linked to biota, including macrophytes to physical habitat quality (Logan & Furse, 2002). There is therefore a clear management need to appraise the sensitivity of European macrophytes to physical habitat alteration.

Man's alterations to rivers through impoundments, realignment of channels, and in-stream engineering works can alter depth, velocity, substrate type, flow types and flow variability (Petts, 1984a; Brookes, 1988). These variables define the physical niches in rivers. Macrophytes have known preferences for these variables (Haslam, 1978; Fox, 1992). Since historic times macrophytes have been grouped by depth preference as emergent, marginal and submerged (Sculthorpe, 1967). In recent times niche separation and range preferences for other physical variables have been demonstrated for many macrophytes (Westlake, 1975; Chambers et al., 1991; French & Chambers, 1996; Dawson et al., 1999a). It is therefore not surprising that studies of physically altered rivers show impacts to macrophyte community structure. Following impoundment and canalisation changes include loss of species, altered species dominance and relative abundance (Petts, 1984b; Baattrup-Pedersen & Riis, 1999).

The point has been strongly made that WFD monitoring programmes need to take into account natural variation if they are not to provide data which leads to misclassification of sites (Irvine, 2004). Irvine argues that only the most sensitive and reliable groups should be monitored. This study aims to address the basic questions as to how macrophyte assemblages vary naturally in relation to physical parameters and do they have potential as indicators of impact to the physical habitat.

We ask a series of inter-related questions. Are known stream macrophyte assemblages associated with different types of physical habitat? Within each macrophyte assemblage can sites of different quality be identified using physical habitat variables? Can sites be assigned to previously identified macrophyte assemblages using site characteristics unlikely to be affected by man? Are macrophyte metrics sensitive to physical habitat alteration and is it possible to identify indicator species?

This work, is part of a much wider study supporting the implementation of the WFD, the EU funded Standardisation of River Classification (STAR) Project which has the aim of developing standardised, statistically robust monitoring methods, for use across Europe Furse et al. (2006). To answer the questions outlined above we analysed survey data from 107 stream sites across Europe collected during the STAR project. The sites were known to represent a wide range of physical habitat quality from highly degraded to un-impacted.

All three major stream macrophyte assemblages were represented which are; (C4) mountain streams poor in species and dominated by mosses and liverworts, (C6) lowland streams dominated by *Phalaris arundinacea* and *Sparganium emersum* and (C7) an intermediate group rich in species with many amphibious species, terrestrial dicotyledons and mosses (Baattrup-Pedersen et al., 2006).

Methods

Study sites

The sites included in the present investigation covered an impact gradient from sites having high ecological quality to sites having poor and bad ecological quality (*sensu* WFD). The WFD has 5 classes bad, poor, moderate, good and high (reference), which we coded 1 to 5 respectively. Sites were chosen that were either un-impacted (ecological quality class 5) or the major impact was hydro-morphological degradation (ecological quality class 1–4). Hydro-morphologically degraded sites included realigned, impounded and over-deepened reaches. The allocation of sites to an ecological degradation class was performed *a priori* according to criteria described in Furse et al. (2006). A total of 107 sites were included in the analysis. They were located in Austria, Czech Republic, Germany, United Kingdom, Denmark, France, Greece, Italy, Latvia and Poland, see map in Furse et al. (2006).

A system, River Habitat Survey (RHS), for assessing the character and quality of rivers based on their physical structure has been developed in the UK (Raven et al., 1997). Any 500 m length of river surveyed using RHS methodology can be categorised and its habitat quality assessed by comparison with other sites of a similar physical character. RHS was used within the STAR project and surveying was undertaken in late summer/early autumn together with supporting chemical, physico-chemical and geographical elements. The RHS survey records information on macrophytes as the abundance of ten attribute groups. The groups are, Liverworts/mosses/lichens, emergent broad leaved herbs, emergent reeds/sedges/rushes/grasses/horsetails, floating-leaved (rooted), free-floating, amphibious, submerged broad-leaved, submerged linear-leaved, submerged fine-leaved and filamentous algae. The attribute groups were used in the analysis.

Species level macrophyte data was also recorded using a separate survey technique at the same site. The macrophyte survey method was a version of the Mean Trophic Rank Methodology developed for the STAR project (Dawson et al., 1999b). Species present in mainland Europe, but not in the UK where the survey was originally developed, were added to the form. The survey methods are available at the STAR website (www.eu-star.at) under the public-access section "Protocols". As well as recording species data the MTR survey records categories of bed stability, substrate type, river width, and water depth.

Data analysis

Allocation of stream sites to biological groupings
Discriminant analysis was used to allocate sites to the macrophyte groupings previously identified for un-impacted European streams (TWINSPAN predictor group C4 (mainly mountain sites), C6 (mainly lowland sites) and C7 (intermediate)); see Baattrup-Pedersen et al. (2006); Jongman et al. (1987). Four ecoregion/catchment scale variables, which showed significant differences between the TWINSPAN predictor group C4, C6 and C7 reference sites, were used. These were altitude, reach slope, distance to source and height of source. The ability of the variables to discriminate between the groups was tested individually and in combination. Height of source performed better than the other individual variables and better than the variables in combination. It correctly allocated 79% of reference sites to their correct group.

The new groups contain both un-impacted and impacted sites. To differentiate between them and the original groups which only contain un-impacted sites, the new groups were named, Discrim4 (near source), Discrim6 (far from source) and Discrim7 (intermediate).

Sites from a particular *a priori* defined stream type were usually all assigned to the same TWINSPAN group. Sites from some *a priori* stream types were split between TWINSPAN groups 4 and 7 (see Baattrup-Pedersen et al., 2006). They were all small mountain streams in the Czech Republic (Type 5), Germany (Type 4) and Italy (Type 6).

Hydro-morphological site characteristics
Three main types of hydro-morphological impacts, from the same sites, were distinguished in the RHS. These included channel realignment, over-deepening and impoundment. The level of impact varied among the affected reaches depending on the channel length being affected. In addition some sites were subjected to more than one type of impact. Table 1 gives an overview of the number of sites within each of the predicted groups that were impacted by the different impact types.

The three types of impacts may affect macrophyte communities differently. For example average flow velocity may decrease in over-deepened reaches which may stimulate growth of emergent species at the edges of the channel. In contrast the velocity may increase and be more homogeneous in straightened reaches, which may stimulate growth of submerged species that are highly resistant to flow e.g. species with linear growth morphologies such as *Ranunculus pencillatus pseudofluitans*. To get a thorough description of the major impact types we therefore needed to calculate several hydro-morphological variables based on the RHS & MTR data.

We used 4 different types of hydro-morphological variables with the aim of including measures of system complexity i.e. domination, diversity, score and homogeneity. These variables were calculated for each of the 5 main hydro-morphological descriptors, e.g. bed stability, water depth, substrate, RHS flow types and (wetted) width. These descriptors are recorded as categories. A value between 1 and 9 was allocated to the possible categories within each of the descriptors

Table 1. Overview of the number of sites impacted by the three major impact types in the RHS within each of the predicted groups

	Discrim4 (near source)	Discrim6 (far from source)	Discrim7 (Intermediate)
Impounded	1	0	0
Realigned	2	3	2
Over-deepened	5	6	3
Impounded and realigned	2	0	1
Impounded and over-deepened	2	1	0
Realigned and over-deepened	7	2	8
Realigned, over-deepened and impounded	1	2	1

(Table 2). Domination expresses the dominant category, diversity the number of categories represented, score the weighted average of the categories represented and homogeneity the distribution of the categories represented.

The score was calculated as:

$$\mu = \frac{\sum_{i=1}^{N} i \cdot n_i}{\sum_{i=}^{N} n_i},$$

where
N = the number of categories represented, and
n_i = the percentage of reach in category i

The homogeneity was calculated as:

$$I = N \cdot \mu^2 \sum_{i=1}^{N} \frac{(n_i - \hat{m}_i)^2}{m_i},$$

where

$$\hat{m}_i = \frac{\sum_{i=1}^{N} n_i}{N}$$

is the mean percentage for each category in the case of equal representation.

A high homogeneity therefore implies that the distribution of categories is very uniform whereas a low homogeneity implies that the distribution is heterogeneous.

A Principal Components Analysis (PCA) ordination on the calculated hydro-morphological variables was performed to describe habitat characteristics of the investigated stream sites Jongman et al. (1987). To test whether the calculated hydro-morphological variables were able to distinguish between the macrophyte assemblages predicted using discriminant analysis earlier, as Discrim4 (near source), Discrim6 (far from source) and Discrim7 (intermediate), an ANOVA was performed. Relationships between PCA axis 1 and 2 and the hydro-morphological variables were furthermore analysed by Spearman Rank correlation analyses. In the PCA diagram the environmental vectors are exaggerated by 5 to make their relative importance (their lengths) obvious.

Additionally, we tested the ability of the calculated hydro-morphological variables to detect and assess hydro-morphological degradation. Each site was *a priori* allocated to an ecological

Table 2. Categories of hydro-morphological descriptors derived from RHS and MTR. The allocated values are on an ordinal scale and are used in domination, diversity, score and homogeneity calculations

Hydormor-phological descriptor	Allocated value								
	1	2	3	4	5	6	7	8	9
MTR Bed Stability	Firm	Stable	Unstable	Soft					
MTR Depth	< 0.25 m	0.25–0.5 m	0.5–1.0 m	> 1.0 m					
MTR Substrate	Bedrock	Boulders/cobbles	Pebbles/gravel	Sand	Silt				
RHS Flow	Free-fall	Chute	Chaotic	Unbroken standing waves	Broken standing waves	Upwelling	Rippled	Smooth	No perceptible flow
MTR Width	< 1 m	1–5 m	5–10 m	10–20 m	> 20 m				

quality class (1–5) according to Furse et al. (2006). To test whether the hydro-morphological variables varied among the ecological quality classes a One Way ANOVA with Bonferroni corrections was performed separately on Discrim4, Discrim6 and Discrim7 sites. To attain comparable classes in terms of number of sites included we chose to divide the *a priori* site classification into three groups i.e. ecological quality class 1, 2 and 3 (EQ1–3), ecological quality class 4 (EQ4) and ecological quality class 5 (EQ5). Achieving sufficient sample size for analyses and homogeneity of response within groups were the main criteria for dividing the groups.

Macrophyte communities
Various macrophyte attribute groups were derived directly from the RHS and include amphibious species, emergent broad-leaved herbs, emergent reeds/sedges/rushes, filamentous algae, floating-leaved (rooted) species, free-floating species, liverworts/mosses/lichens, submerged broad-leaved, submerged fine leaved and submerged linear leaved species (Environment Agency, 2003). In addition the structural metrics, species richness, domination and evenness were used to describe community structure, see Baattrup-Pedersen et al. (2006) for definitions of structural metrics. These were all derived from the MTR indexation (Dawson et al., 1999b; Szoszkiewicz et al., 2006).

To analyse relationships between hydro-morphological degradation and macrophyte communities, Spearman Rank correlation analyses were performed between hydro-morphological variables that separated ecological quality classes and attribute groups and structural metrics. In addition, a Canonical Correspondence Analysis (CCA) using CANOCO 4.5 (ter Braak & Smilauer, 1998) was performed to detect individual species or groups of species indicative of hydro-morphological degradation. A down-weighting of rare species was chosen in the analysis. All calculated hydro-morphological variables were included in this analysis initially and the best predictors were selected by forward selection, which is a multivariate extension of the stepwise regression method.

All other statistical analyses were carried out using Minitab software, Minitab (2004).

Results

Hydro-morphological site characteristics

The first three components of the PCA applied to the 20 hydro-morphological variables explained 62% of the variance in the system (PCA 1 40%, PCA 2 13% and PCA 3 9%). Stream sites from discriminant group 4 (near source), 6 (far from source) and 7 (intermediate) were primarily separated along PCA axis 1 (Fig. 1). Discrim6 sites were significantly separated from Discrim4 and Discrim7 sites (ANOVA, $p < 0.05$). Discrim4 and Discrim7 on the other hand were not significantly separated (ANOVA, $p > 0.05$). The hydro-morphological characteristics separating the predicted groups were related to several of the calculated variables (Fig. 1; Table 3). We found that Discrim4 sites were much more hydro-morphologically diverse than Discrim6 sites in terms of substrate, flow and stability characteristics. In accordance the homogeneity in both water depth and substrate characteristics was higher in Discrim6 sites. Discrim6 sites were also deeper and had a predominance of finer substrates compared to Discrim4 sites (data not shown).

The overall environmental variability, across all the hydro-morphological variables, assessed from PCA 1 site scores was highest in un-impacted Discrim6 and Discrim7 sites (EQ 5) (Fig. 2; Table 4). PCA site scores could not be used to differentiate ecological quality in Discrim4 and Discrim7 (ANOVA, $p > 0.05$). In contrast, PCA site scores could be used to differentiate ecological quality in Discrim6 (Fig. 2). Thus, PCA 1 site scores were significantly higher in EQ1–3 compared to EQ 5 (ANOVA $p < 0.05$; Table 4). Further EQ4 PCA 1 site scores were intermediate between EQ1–3 and EQ5 site scores (Table 4).

Several of the calculated hydro-morphological variables could also be used separately to distinguish among ecological quality classes. In Discrim4 the substrate diversity decreased significantly with decreasing ecological quality (Fig. 3a; ANOVA $p < 0.05$). In Discrim6 the homogeneity in substrate and water depth characteristics increased with decreasing ecological quality class (ANOVA $p < 0.05$; Fig. 3b). In addition, the substrate was also finer and less diverse in sites with low ecological quality compared to sites

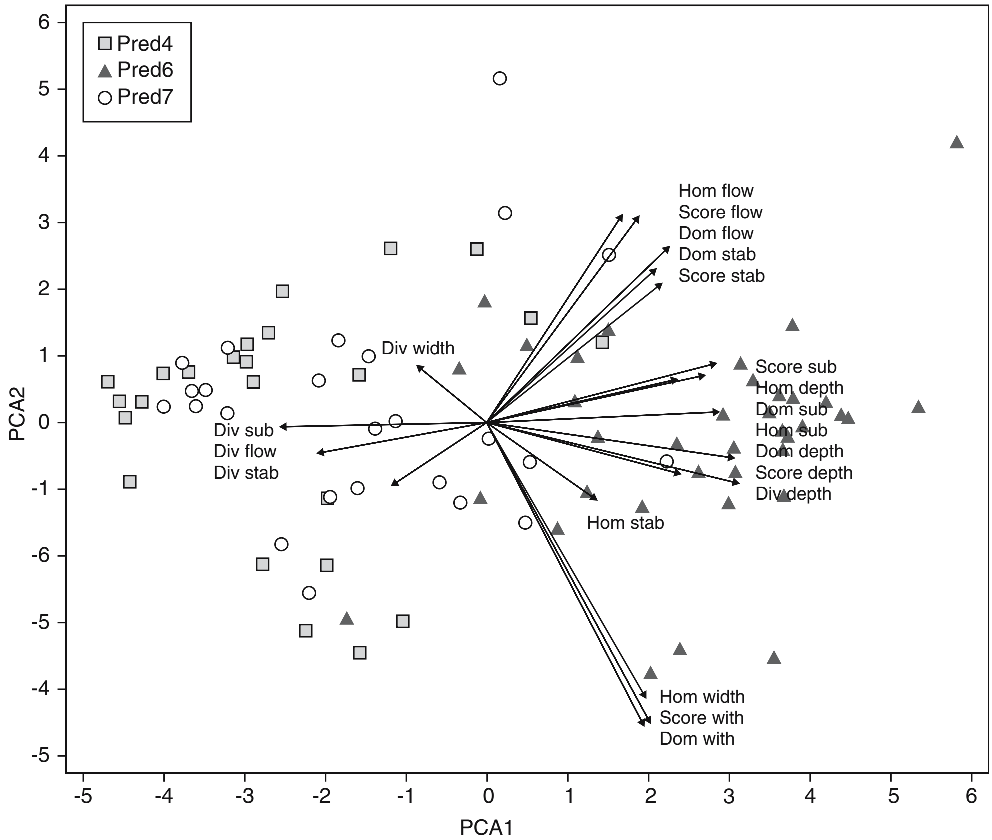


Figure 1. Principal component analysis (PCA) ordination of the calculated hydro-morphological variables from RHS/MTR in 107 stream sites distributed throughout Europe. Different symbols denote different discriminant groups 4, 6 and 7 respectively. These groups were identified from a discriminant analysis performed to predict biological communites (TWINSPAN groups – see data analysis section and Baattrup-Pederesen et al., 2006). The discriminant analysis was based on altitude, distance to source and height of source. Environmental vectors are exaggerated 5 times. Depth = water depth, Div = diversity, Dom = Domination, Flow = RHS flow category, Hom = homogeniety, Stab = bed stability, Score = weighted average of categories represented Sub = Substrate, and width = wetted width.

with high ecological quality (ANOVA $p < 0.05$; Fig. 3b). In Discrim7 depth characteristics changed in response to hydro-morphological impact. Both the score and the dominant depth decreased in sites with low ecological quality compared to sites with high ecological quality (Fig. 3c).

Linkages between macrophytes and hydro-morphological site characteristics

Spearman rank correlation analyses were used to identify linkages between macrophyte attribute groups/structural metrics and hydro-morphological site degradation. We only performed the analysis with hydro-morphological descriptors that separated ecological quality classes e.g. diversity in substrate types in Discrim4, homogeneity in depth and substrate characteristics and dominant depth and substrate type in Discrim6, and score and dominant water depth in Discrim7 (see Fig. 2). In Discrim4, we did not find any significant relations between diversity in substrate and the various attribute groups or structural metrics (see data analysis section). In Discrim6 the attribute group liverworts/mosses/lichens correlated negatively to both homogeneity in depth ($r = -0.452$), dominant depth ($r = -0.519$) and dominant substrate ($r = -0.465$) ($p < 0.05$; Table 5). Species richness decreased with increasing substrate homogeneity ($r = -0.324$) and the

Table 3. Significant correlation coefficients ($p < 0.05$) between PCA axis scores and hydro-morphological variables calculated from RHS

	PCA1	PCA2	PCA3
Bed Stability_Domination	0.623	0.213	−0.283
Bed Stability _Score	0.587	0.246	−0.257
Bed Stability _Diversity	−0.322		
Bed Stability_Homogeneity	0.361	−0.281	−0.409
Depth _Domination	**0.854**		
Depth_Score	**0.875**	−0.234	
Depth_Diversity	**0.688**		
Depth_Homogeneity	0.630		
Substrate_Domination	**0.770**		−0.267
Substrate_Score	**0.793**		−0.362
Substrate_Diversity	−0.709		
Substrate_ Homogeneity	**0.824**		
Flow_ Domination	0.548	0.293	0.297
Flow_ Score	0.540	0.346	0.358
Flow_ Diversity	−0.594		−0.305
Flow_ Homogeneity	0.643	0.326	0.372
Width_Domination	0.583	−0.732	
Width_ Score	0.603	−0.672	
Width_ Diversity	−0.212		−0.557
Width_Homogeneity	0.562	−0.602	0.350

See data analysis section for further explanation. Correlation coefficients above 0.650 (arbitrary threshold) are marked in bold.

evenness in species distribution increased with increasing homogeneity in water depth ($r = 0.397$; $p < 0.05$; 5). In Discrim7 several attribute groups correlated significantly with the depth score (submerged broad-leaved, liverworts/mosses/lichens, emergent reeds/sedges/rushes and amphibious species; Table 5). Similarly emergent reeds/sedges/rushes correlated significantly with dominant depth ($p < 0.05$; Table 5).

We performed a CCA to identify species or groups of species associated with hydro-morphological degradation. The eigenvalues of the CCA were 0.569, 0.263 and 0.209 for axis 1, 2 and 3 respectively (Fig. 4). Of the 20 hydro-morphological variables initially considered in the CCA (Table 3), 7 were retained in the analysis by forward selection. In Figure 4 significant variables are included as arrows that point in the direction of maximum change. We did not find any clear separation of ecological quality sites along the CCA axes in Discrim4 and Discrim7. In Discrim6, on the contrary, increasing water depth and substrate fineness were highly related to hydro-morphological degradation (Fig. 4a). Species associated with these variables were *Elodea canadensis*, *Sparganium emersum* and *Potamogeton crispus* (Fig. 4b). They are all submerged species.

Discussion

The physical habitat of the three-macrophyte assemblages, separated by discriminant analysis using the variable 'distance to source' examined is different. Discrim7 sites were intermediate in physical character to those in Discrim4 and Discrim6. A similar pattern exists for reference sites alone; C4 sites are small, shallow, upland streams, C6 sites medium sized lowland streams and C7 sites were intermediate in nature Baattrup-Pedersen et al. (2006).

Impacted sites are less physically diverse than non-impacted sites. This observation is consistent with physical characteristics associated with impounded waters, channel realignment and over-deepening (Environment Agency, 2003). The accumulation of fines at impacted Discrim6 sites also implies the system is characteristic of water

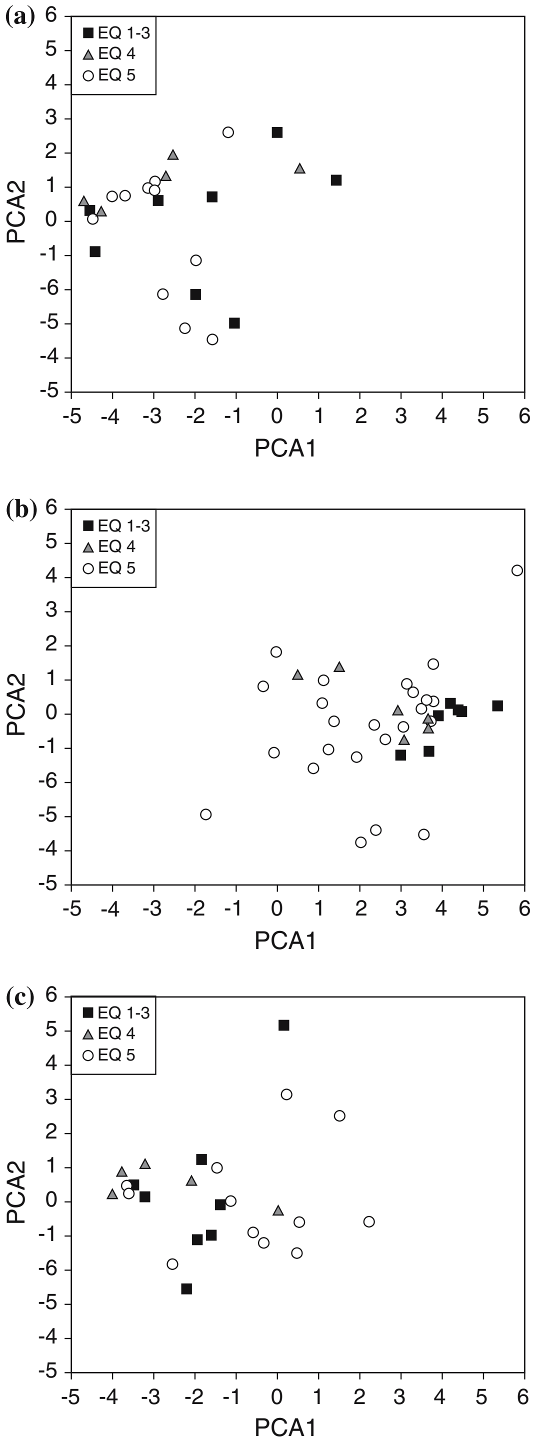


Figure 2. Site scores from PCA (see Fig. 1) superimposed by ecological quality (EQ) class in Discrim4 (plot a), Discrim6 (plot b) and Discrim7 (plot c) respectively. The ecological quality class was predicted in each site prior to the investigation from the degree of hydromorphological degradation (see method section). Ecological quality classes 1, 2 and 3 being moderate, poor and bad respectively, are grouped together.

Table 4. Mean and Standard Deviation of PCA axis scores in ecological quality class 1–3 (EQ 1–3), ecological quality class 4 (EQ 4) and ecological quality class 5 (EQ 5 = reference) in Predicted group 4, 6 and 7

	PCA1	PCA2	PCA3
Discrim4			
EQ 1–3	−1.898 ± 5.998	−0.077 ± 5.610	−0.610 ± 3.855
EQ 4	−2.734 ± 5.254	1.161 ± 1.666	0.848 ± 2.056
EQ5	−2.823 ± 3.288	−0.242 ± 6.085	−0.358 ± 4.835
Discrim6			
EQ 1–3	**4.158 ± 2.362a**	−0.227 ± 1.522	−0.122 ± 1.501
EQ 4	**2.567 ± 3.178ab**	0.243 ± 2.145	−0.867 ± 1.610
EQ5	**2.090 ± 7.561b**	−0.328 ± 7.975	0.084 ± 4.819
Discrim7			
EQ 1–3	−1.938 ± 3.646	0.288 ± 7.741	0.247 ± 4.894
EQ 4	−2.612 ± 4.035	0.532 ± 1.365	−0.189 ± 2.274
EQ5	−0.691 ± 5.895	0.070 ± 4.971	0.626 ± 4.894

For further explanation see data analysis section. Means in bold are significantly different (ANOVA with Bonferroni correction; $p < 0.05$).

where flow has been reduced because of downstream impoundment or over-deepening. Habitat diversity increases the number of niches available to aquatic organisms in freshwaters (French & Chambers, 1996; Vinson & Hawkins, 1998). The loss of habitat diversity is expected to lead to a loss in macrophyte diversity.

Metrics were successfully linked to hydromorphological factors associated with site degradation. The attribute group liverworts/mosses/lichens was correlated with water depth and substrate characteristics for Discrim6 and Discrim7 sites. This result accords with studies, over a wide geographic area, that show the diversity of bryophytes in rivers is associated with depth and substrate (Suren & Duncan, 1999; Scarlett & O'Hare, 2006).

The negative correlation of liverworts/mosses/lichens with homogeneity of water depth, deep water (the dominant depth) and fine particle sub-

Table 5. Significant Spearman rank correlation coefficients between hydro-morphological variables that separates ecological quality classes (EQ 1–3, 4 and 5) calculated from RHS and macrophyte attribute groups/structural metrics within Discriminant group 6 and 7. $N = 38–39$

RHS calculated variable	Attribute group/metric	Correlation coefficient	*p*
Discrim6			
Hom_depth	Liverworts/mosses/lichens	−0.452	0.0039
	Evenness	0.397	0.0135
Hom_sub	Species richness	−0.324	0.0439
Dom_sub	Liverworts/mosses/lichens	−0.465	0.0029
	Filamentous algae	−0.363	0.0233
Dom_depth	Liverworts/mosses/lichens	−0.519	0.0007
Discrim7			
Score_depth	Submerged broad-leaved	0.407	0.0353
	Liverworts/mosses/lichens	0.383	0.0486
	Emergent reeds/sedges/rushes	0.495	0.0086
	Amphibious species	0.400	0.0384
Dom_depth	Emergent reeds/sedges/rushes	0.358	0.0483

No significant correlation coefficients were found in Discrim4.

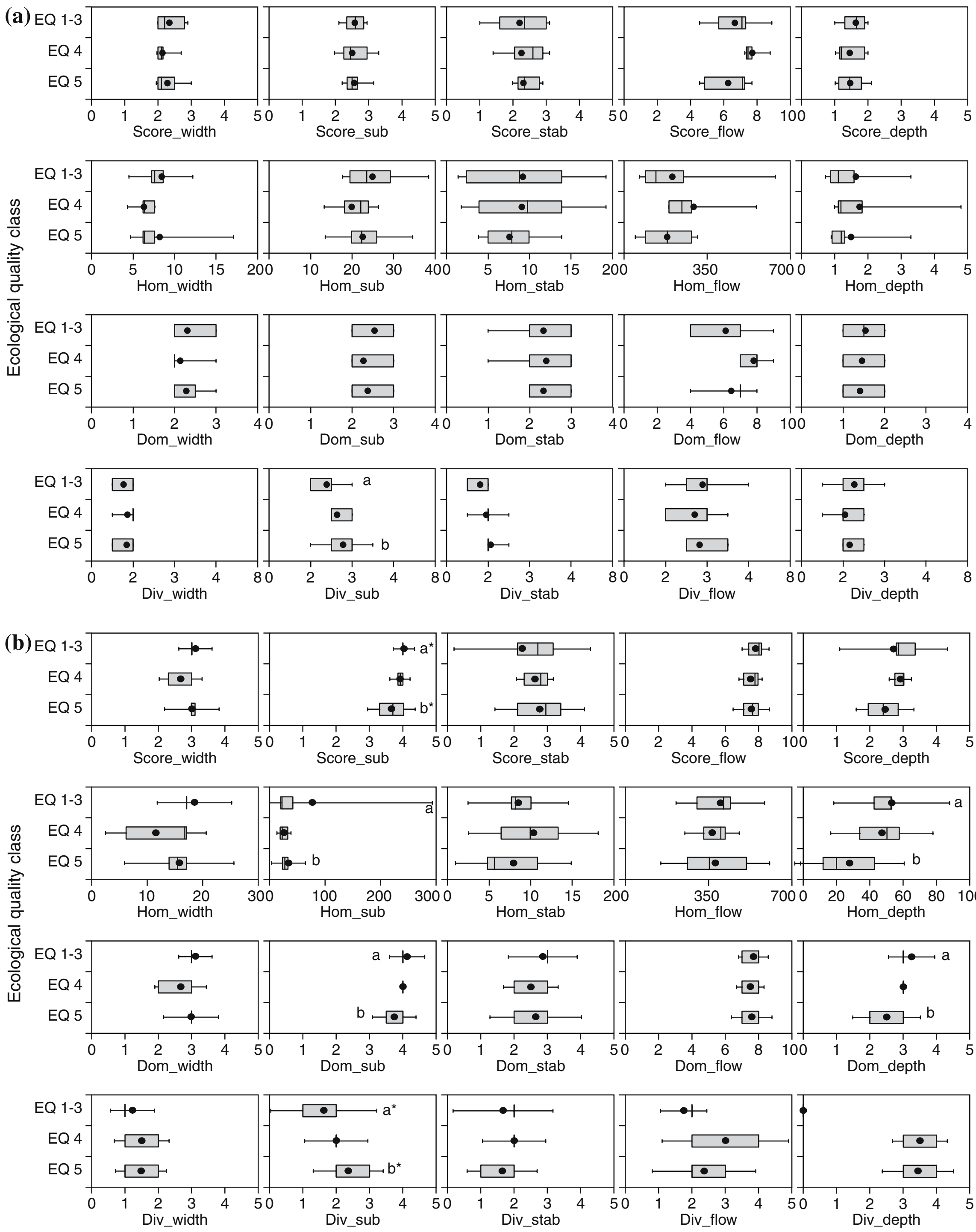


Figure 3. Box-whisker plots of hydro-morphological variables calculated from RHS/MTR for Discrim4 (plot a), Discrim6 (plot b) and Discrim7 (plot c) respectively. Letters signify differences between mean values (ANOVA with Bonferroni correction, $p < 0.05$). Letters with *indicate that $p < 0.10$. The box represents 10%, 25%, 75% and 90% and the symbol the mean value. Error bars represent the 5% and 95% percentiles. Abbreviations of environmental variables are given in Table 2. The homogeneity score was divided by 1000 in all cases to make the graphic presentation easy to read. The legend to Fig. 1 provides a key to the codes used in the diagram.

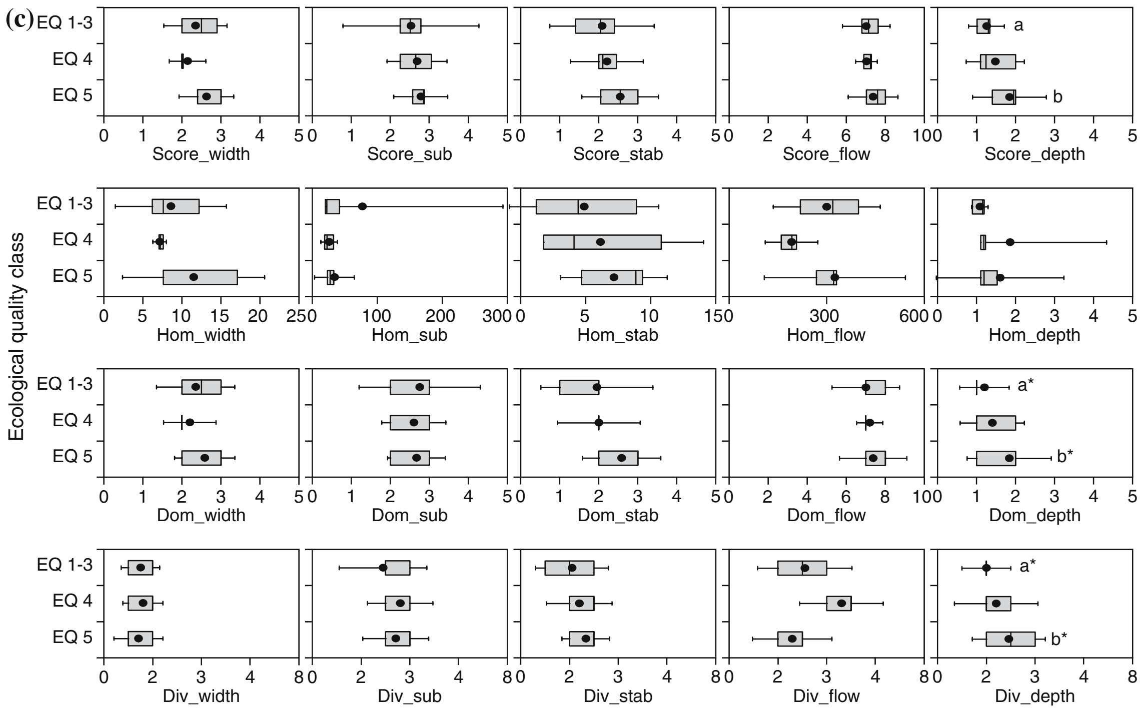


Figure 3. (Continued)

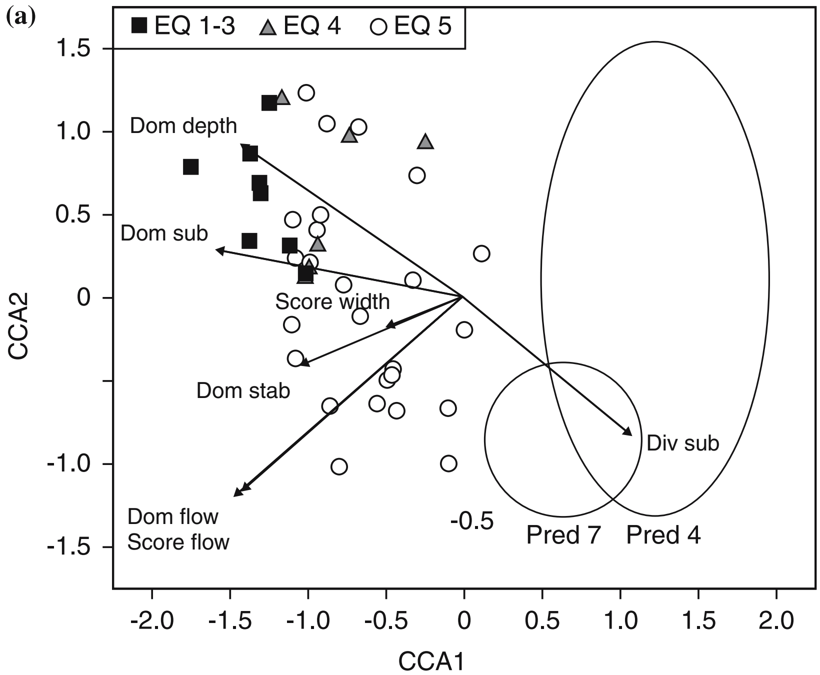
strate (the dominant substrate) implies increasing abundance of this group is indicative of sites which are probably not over-deepened. Equally, the responses of species richness and evenness to depth and substrate homogeneity also suggest they have the potential to be used as metrics.

The ordination analysis indicates that a number of species are tolerant to habitat degradation, e.g. *Sparganium emersum, Potomogeton crispus*, and *Elodea canadensis*. These species are also tolerant to other types of impacts, such as organic pollution and weed cutting (Battrup-Pedersen et al., 2003; Dawson et al., 1999b; Scneider & Melzer, 2003). Their value as indicators of degradation is therefore unspecific and should be augmented by combining them with other measures like evenness in species distribution.

Most of the species associated with physical variables that distinguish between ecological quality classes are present in both impacted and unimpacted stream sites (see Baattrup-Pedersen et al., 2006). However, these species may exhibit different abundances and spatial distributions in impacted as compared to un-impacted stream sites. To analyse this question properly would require the relationship to be tested on a larger dataset.

Other future work could potentially include using a revised sampling strategy. Previous investigations demonstrated that the spatial distribution of macrophytes in lowland stream reaches changes in response to physical degradation or impact (Baattrup-Pedersen et al., 2002; Wright et al., 2003). The STAR sampling methodology (MTR & RHS) does not allow distribution changes within reaches to be examined. This issue should be investigated in more detail, e.g. by applying the 'rectangle method' described by (Wright et al., 1981).

In conclusion, the presence of some species like *Fontinalis antipyretica* and metrics such as the presence of liverworts/mosses/lichens may indicate that a site is un-impacted by hydro-morphological degradation. Equally other taxa and metrics have been shown to be tolerant to degradation. Therefore, there is the basis for the evolution of a combined expression using both tolerant and sensitive species which distinguish degraded from un-impacted sites.



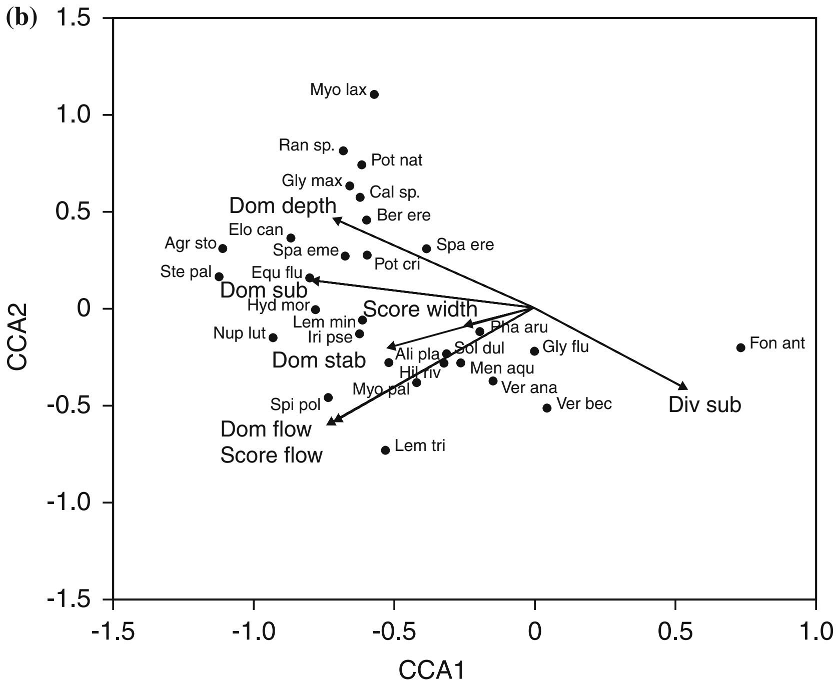


Figure 4. Canonical Correspondence Analysis (CCA) ordination of 107 stream sites distributed throughout Europe. (a) Sample scores of Discrim6 sites are shown with symbols, whereas mean values and one standard deviation of sample plot scores for Discrim4 and Discrim7 sites are shown as spheres. Different ecological quality classes are superimposed on the figure for Discrim6. (b) Species scores of species present in at least 4 Discrim6 stream sites. Only significant vectors are included on the figure forward selected by CANOCO version 4.5. The legend to Fig. 1 provides a key to the codes used in the diagram.

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